INFORMATION ON NGDC/GFZ CANDIDATE MODELS FOR IGRF-10 BY MAUS ET AL

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Due to the simultaneous availability of CHAMP and Oersted vector data, we submit separate CHAMP and Oersted models, as well as a combined model. To improve long term stability, our combined model candidate for SV 2007.5 also includes observatory annual means since 1995.5.

Candidates for the static field in 2005:
    1) CHAMP-only model extrapolated to 2005.0
    2) Oersted-only model extrapolated to 2005.0
    3a) A combined CHAMP and Oersted model extrapolated to 2005.0

Candidates for SV in 2007.5:
    1) CHAMP-only model, SV extrapolated to 2007.5
    2) Oersted-only model with sv extrapolated to 2007.5
    3b) A combined model from CHAMP, Oersted and Observatory annual
        means since 1995.0. The SV is extrapolated to 2007.5

The coefficients are taken as subsets of higher degree models, with the static Gauss coefficients (g) to degree 36, secular variation (g') to degree 16 and the change in the secular variation (g") to degree 12.

Input data:

    1. CHAMP data from Aug-2000, scalar to July/04, vector to April/04
    2. Ørsted scalar and vector data from April/1999 to July/04
    3. Observatory annual mean differences from 1995.5 to 2003.5

Instrument correction:

For CHAMP, a time varying set of misalignment corrections was estimated previously, and was applied to the CHAMP vector data before estimating the model coefficients. The correction code is available at http://www.gfz-potsdam.de/pb2/pb23/SatMag/suppl.html. Oersted vector data are already calibrated for mis-alignments.

Plasma correction:

The CHAMP data were corrected for the diamagnetic effect using the electron density and temperature provided by the Langmuir Probe (Luehr et al., 2003, GRL). This correction cannot be applied to Oersted data due to the lack of electron density and temperatures. However, due to Oersted's higher altitude, the plasma effect is much smaller.

Tidal correction:

The ocean tidal magnetic field was subtracted from all CHAMP and Oersted satellite data using predictions of Kuvshinov.

What were the data selection and rejection procedures?

The following criteria were applied:
1. $K_p \leq 1+$, $K_p \leq 2$ for previous 3h
2. $|Dst| < 30nT$, $|d(Dst)/dt| < 3nt/h$ in previous 3h
3. For polar latitudes: $|IMF-By| < 8nT$
4. For polar latitudes: $-2nT < IMF-Bz < 6nT$
5. For mid latitudes: Vector data only up to 50 deg Mag Lat
6. For internal field: Sun at least 5 deg below horizon
7. For CHAMP mid latitude: 22:00 < LT < 5:00
8. For Oersted mid latitude: 21:00 < LT < 5:00
9. All satellite data were checked for outliers against an initial field model (POMME-2.1)
10. Observatory annual means were plotted in terms of SV and noisy stations were eliminated

External Fields:

External fields are largely sun-synchronous. Consequently, they are best described in Solar Magnetic (SM) and Geocentric Solar Magnetospheric (GSM) coordinates. Since it is not possible to estimate a sun-synchronous degree-2 external field from night side data alone, the external field was estimated from a data set with full local time coverage. It was then subtracted from the night side data before estimating the internal field.

Our external field has 12 coefficients:
1. A Y1,0 coefficient in SM for the steady ring current
2. A scaling factor for the Est/Ist dynamic ring current correction (Maus and Weidelt, 2004, GRL)
3. Two coefficients accounting for IMF-By correlated fields (Lesur, Macmillan and Thomson, GJI in print), giving the correlation between IMF-By and uniform fields Y1,1 and Y1,-1 in GSM.
4. Eight coefficients for a stable degree-2 external field in GSM

The GSM fields are coupled to the corresponding induced fields in GEO, using the semi-global Earth conductivity model (model B) of Utada et al. (GRL, 2003). Induced fields with multi-annual and multi-diurnal periods were therefore not separately parameterized.

These 12 coefficients were determined from CHAMP and Oersted scalar data at all latitudes and local times, with added CHAMP and Oersted vector data at mid latitudes and all local times. The determined values are:

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SM-Stable external field:    7.5409    0.0000    0.0000
Scaling factor for Est/Ist:  0.7802
GSM-External field:
Deg-1:   13.1498    0.1978    0.0206
Deg-2:    0.1118   -0.1065    1.3100   -0.1368    0.2126
IMF-By correlations for Y1,0 and Y1,-1 in GSM:  0.1197   -0.2330
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How was any interpolation or extrapolation to epoch done?

Static: The Gauss coefficients of the static field at 2005.0 were obtained by evaluating the model up to degree 13 as $g(t) = g + tg' + 0.5\ t^2\ g''$, where t=0 in 2002.5.

SV: For the SV at 2007.5, the SV coefficients were predicted as g'(t) = g' + tg'', where t=0 in 2002.5.

What weights were allocated to the different sorts of data?

The individual data were weighted to achieve equal area weight over the sphere within each data set. The anisotropic co-variance matrix for Oersted was normalized to unity. Furthermore, the sum of all weights within one data set was normalized to unity.

Model 1:
50% CHAMP scalar data, global coverage
50% CHAMP vector data, mid latitude coverage

Model 2:
50% Oersted scalar data, global coverage
50% Oersted vector data, mid latitude coverage
polar gaps filled with scalar CHAMP data

Model 3a:
25% CHAMP scalar data, global coverage
25% CHAMP vector data, mid latitude coverage
25% Oersted scalar data, global coverage
25% Oersted vector data, mid latitude coverage

Model 3b:
23% CHAMP scalar data, global coverage
23% CHAMP vector data, mid latitude coverage
23% Oersted scalar data, global coverage
23% Oersted vector data, mid latitude coverage
8% Observatory annual mean differences

What, if any, regularisation was used?
- No regularisation for g
- Degrees 14-16 of g' were damped to impose a decreasing spectrum of g'
- Degrees 11-12 of g" were damped to impose a decreasing spectrum of g".

What was the method used to solve the Least Squares equations?
Direct solver, via Eigenvectors and Eigenvalues of A^TA. The anisotropic covariance initially used for Oersted vector data was finally dropped because the anisotropic weighting was found to increase model errors, in particular for the later data periods. This will be investigated further.

Estimate of model errors:

With the simultaneous availability of CHAMP and Oersted data, separate models have been estimated from both data sets. The difference between the coefficients are provided as error estimates in the tables of submitted model coefficients. For the combined models, we use the RMS of the differences of the combined model to the individual Oersted and CHAMP models. The following table lists the mean field difference |d**B**| over the surface of the Earth, as given by the square root of the sum of the Mauersberger/Lowes powers of the coefficient differences:

Model1 – Model2	2002.5	2005	2007.5	2010
Static field to degree 13	3.07 nT	7.51 nT	30.42 nT	70.01 nT
SV to degree 8	1.1 nT/a	5.9 nT/a	12.0 nT/a	18.2 nT/a

Table 1: Mean vector field differences between independent CHAMP and Oersted models at the Earth's surface

Verification of model error by hind casting previous DGRFs

Since there is no obvious reason why the geomagnetic field should behave differently for forward and backward directions in time, presumed model errors for the future can be assessed by hind casting the known field of the past. Figure 1 shows the result for the CHAMP (model 1), Oersted (model 2) and the combined CHAMP/Oersted/observatory model (model 3b). To put the poor CHAMP performance into context, a model from only Oersted data of the same period performs even worse. The dashed lines show the result when the acceleration is not used, which is equivalent to using the SV at 2002.5 as an estimate for hind- and forecasting the field. The hind cast analysis suggests that using the secular acceleration can improve the forecast of the field for periods of up to 15 years, if more than five years of data coverage are available.
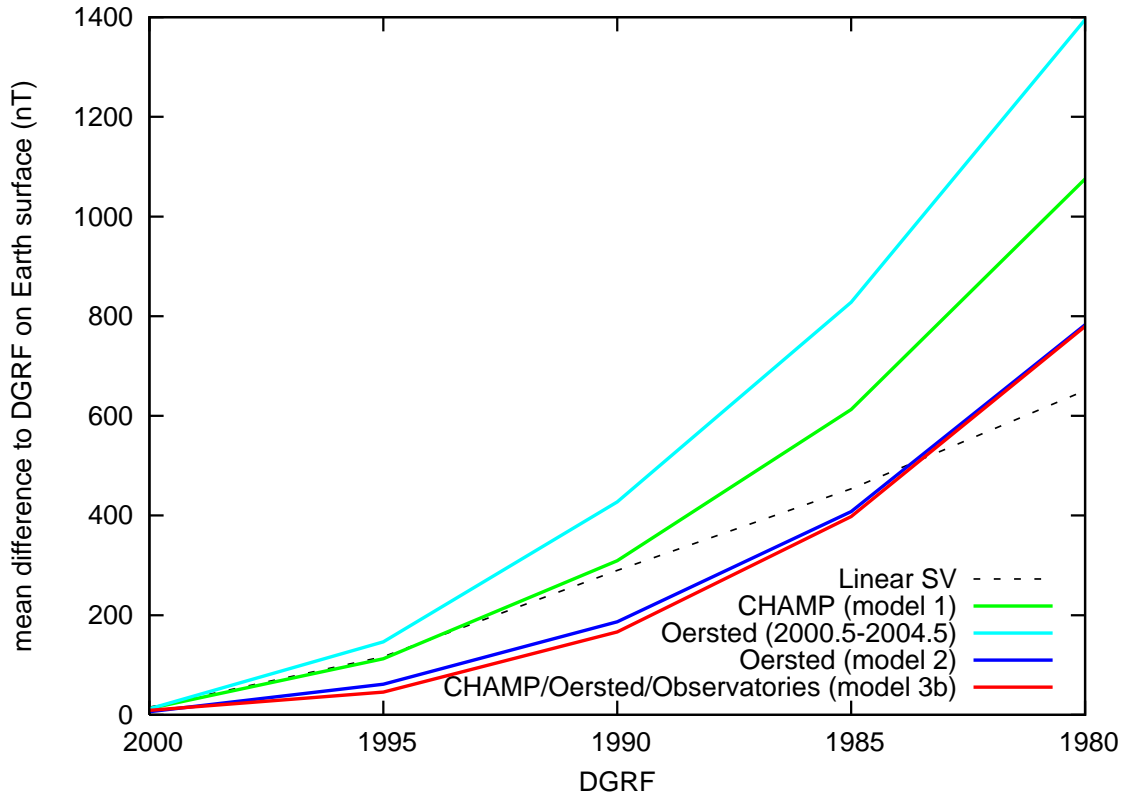

Figure 1: Mean vector field difference over the Earth's surface between our models and previous DGRFs. The model performance may be influenced by the data quality, length of the data period (stability), as well as by the proximity of the nearest measurement (2000.5 for model 1, 1999.2 for model 2, 1995.5 for model 3b).